DECLARATION

I, Atsushi Yasuno, of Yanagida & Associates, 7F Shin-Yokohama KS Bldg., 3-18-3 Shin-Yokohama, Kohoku-ku, Yokohama-shi, Japan, hereby certify that I understand both the English and Japanese languages, that the attached is a true and correct translation of the priority document, and that all statements are being made with the knowledge that willful false statements and the like are punishable by fine, imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

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[Name of Document] Specification

[Title of Invention]

Surface emitting Semiconductor Laser Element

[Scope of Demand for Patent]

[Claim 1] A surface emitting semiconductor laser element that emits laser light from a surface, comprising:

a GaAs substrate;

semiconductor layers which are formed above said GaAs substrate parallel to said surface, and include:

a lower mirror which is realized by a semiconductor multilayer film formed above said GaAs substrate and constitutes an optical resonator,

an active layer formed above said lower mirror,

a current confinement layer of one of a selective-oxidation type and an ion injection type formed above said active layer, and

an upper mirror which is realized by a semiconductor multilayer film formed above said current confinement layer and constitutes said optical resonator; and

a pair of electrodes which inject current into said active layer;

wherein said active layer includes:

a quantum well made of InGaAsP having a first forbidden bandwidth, and

sublayers arranged adjacent to said quantum well and made of one of InGaP and InGaAsP which has a second forbidden bandwidth greater than said first forbidden bandwidth; and

said lower mirror and said upper mirror are made of AlGaAs.

[Claim 2] A surface emitting semiconductor laser element as defined in claim 1, wherein each of said quantum well

and said sublayers has a composition that lattice matches with GaAs.

[Claim 3] A surface emitting semiconductor laser element as defined in claim 1, wherein said quantum well has a composition that causes compressive strain with respect to GaAs, and each of said InGaP or InGaAsP sublayers has a composition that lattice matches with GaAs.

[Claim 4] A surface emitting semiconductor laser element as defined in claim 1, wherein said quantum well has a composition that causes compressive strain with respect to GaAs, and each of said InGaP or InGaAsP sublayers has a composition that causes tensile strain with respect to GaAs.

[Claim 5] A surface emitting semiconductor laser element as defined in claim 1, wherein said quantum well has a composition that causes tensile strain with respect to GaAs, and each of said InGaP or InGaAsP sublayers has a composition that lattice matches with GaAs.

[Claim 6] A surface emitting semiconductor laser element as defined in claim 1, wherein said quantum well has a composition that causes tensile strain with respect to GaAs, and each of said InGaP or InGaAsP sublayers has a composition that causes compressive strain with respect to GaAs.

[Claim 7] A surface emitting semiconductor laser element as defined in claim 1, wherein said InGaP or InGaAsP sublayers are barrier layers.

[Claim 8] A surface emitting semiconductor laser element as defined in claim 1, wherein said InGaP or InGaAsP sublayers are spacer layers.

[Claim 9] A surface emitting semiconductor laser element as defined in any one of claims 1 through 8, wherein said laser light has a wavelength in a range of 730 to 820 nm.

[Claim 10] A surface emitting semiconductor laser element as defined in any one of claims 1 through 8, wherein said laser light has a wavelength in a range of

770 to 800 nm.

[Detailed Description of the Invention]

[0001]

[Technical Field of the Invention]

The present invention mainly relates to a surface emitting semiconductor laser element which has an emission wavelength in the 780 nm band.

[0002]

[Description of the Related Art]

AlGaAs-based compound surface emitting semiconductor laser elements (vertical cavity surface emitting lasers or VCSEL's), which are formed on GaAs substrates and which have oscillation wavelengths of 850 nm, are commonly used as light sources for use in optical links for short-distance high-speed communications. The main reason why the semiconductor laser elements in the above wavelength band are used is that production of semiconductor laser elements with AlGaAs-based compounds is easy, and the propagation loss through quartz fibers which are mainly used currently is low at the above wavelength band.

[0003]

On the other hand, it is becoming possible to use POF's (plastic optical fibers) in other short-distance communications performed in the home, in or between devices, in automobiles, and in other applications. The POF's have large core diameters, are inexpensive and easy to handle. That is, since the core diameters of the POF's are as large as 100 to 1,000 μm, alignment is easy, and the cost of transmission/reception modules and fiber connectors can be reduced. In addition, it is easy to shape the tips of the POF's and to work with the POF's.

[0004]

POF's are commonly made of PMMA (polymethyl methacrylate). The wavelength ranges, in which the loss

that occurrs in PMMA POF's is low, are limited. In particular, the wavelengths at which semiconductor lasers enabling high-speed communications are available are limited to only three wavelengths, 650, 780, and 850 nm. Especially in the case of semiconductor lasers that emit light having wavelengths of 780 and 850 nm, it is possible to perform various operations on a wafer from formation of a resonator to operational tests, and to use VCSEL elements as light sources, where the VCSEL's can be easily connected to optical fibers. In addition, VCSEL elements that emit light having wavelengths of 850 nm can be manufactured more easily than VCSEL elements that emit light having wavelengths of 780 nm, and it is reported that the reliability of the VCSEL elements that emit light having wavelengths of 780 nm tends to be lower than the reliability of the VCSEL elements that emit light having wavelengths of 850 nm. However, the loss that occurs in PMMA POF's at the wavelength of 780 nm is lower than the loss that occurs in PMMA POF's at the wavelength of 850 nm. That is, light having a wavelength of 780 nm can be transmitted over a greater distance tha light having a wavelength of 850 nm.

[0005]

Considering the above circumstances, in order to suppress the decrease of reliability in the 780 nm band, a VCSEL having a short wavelength range ridge structure and which does not contain aluminum in an active layer has been proposed (refer to, for example, Patent Document 1). Generally, when an active layer is made of AlGaAs containing Al in order to shorten the wavelength, the laser emission efficiency is lowered by increase in non-radiative recombination centers which are produced by mixing of oxygen into AlGaAs during processes for growing crystals and producing elements. In the VCSEL disclosed in Patent Document 1, in order to prevent the decrease in laser emission efficiency, the active layer region is

constituted by an Al-free GaAsP quantum well and GaInP barrier layers. In addition, since GaAsP does not lattice match with the GaAs substrate, and causes tensile strain, the total strain is reduced by GaInP which causes compressive strain.

[0006]

Meanwhile, edge-emitting stripe lasers containing Fabry-Perot resonators and active regions made of AlGaAs are widely used as light sources in CD and CD-R devices. Recently, in order to increase the recording speed in CD-R devices and the like, even laser elements having high output powers exceeding 150 mW have come into use. In the case of edge-emitting stripe laser elements, it is known that Al-free active layers are beneficial for achieving high reliability (refer to, for example, Non Patent Document 1). The most conceivable reason for the benefit of the Al-free active layers is that the reliability of the edge-emitting stripe lasers mainly depends on the stability of cleaved end facets, and the end facets are likely to be oxidized. Further, most of the current AlGaInP-based compound high-power short-wavelength semiconductor lasers have an NAM (non-absorbing mirror) structure, in which light absorption at end facets is suppressed. However, due to recent improvements in crystal growth systems and increases in the purities of raw materials, the quality of AlGaAs crystals are extremely high. Therefore, it is difficult to consider that the quality of AlGaAs crystals is the primary cause of the degradation of the AlGaInP-based compound high-power short-wavelength semiconductor lasers. In particular, in the case of VCSEL's, since no cleaved end facet exists, and no active layer is exposed, no degradation is caused by an end facet.

[0007]

However, in the ridge type VCSEL's as disclosed in Patent Document 1, portions of an active region are

removed by etching. Therefore, there is a possibility that oxidation of surfaces exposed by the removal may affect the reliability of the VCSEL's. In order to prevent the oxidation, VCSEL's having an ion injection type or selective-oxidation type current confinement structure are widely used. In the ion injection type or selective-oxidation type current confinement structure, no portion of an active region is removed by etching. In VCSEL's having an ion injection type current confinement structure, current is confined in an oscillation region located at the center of an active region by injecting ions such as protons to the depth of the upper boundary of the active region except for a current injection region so as to insulate the proton-injected region. In VCSEL's having a selective-oxidation type current confinement structure, current is confined by selectively oxidizing an already formed, AlAs or aluminum-rich AlGaAs layer from the periphery so as to insulate the oxidized portion of the AlAs or aluminum-rich AlGaAs layer. In the latter case, it is necessary to etch off peripheral portions of semiconductor layers. However, since the selectively oxidized portion extends to a great depth from an area of the active layer exposed by the etching, there is almost no influence of non-radiative recombination occurring in the exposed area of the active layer. Alternatively, it is possible to stop the etching performed for the selective oxidation above the active layer so as not to expose the active layer.

[0008]

[Patent Document 1]

Japanese Unexamined Patent Publication No. 9-1017153

[0009]

[Non Patent Document 1]

D. Botez, "High-power Al-free coherent and incoherent diode lasers," Proceedings of SPIE, Vol. 3628 (1999) pp.7

[0010]

[Problem to be Solved by the Invention]

In view of the above circumstances, even in the case of VCSEL's having an active layer made of AlGaAs, the possibility that degradation of crystal quality lowers the reliability of the VCSEL's is considered to be very low. However, even in the case of VCSEL's having an AlGaAs active layer and an ion injection type or selective-oxidation type current confinement structure, VCSEL's having an AlGaAs active layer with higher Al composition and emitting laser light at a wavelength of 780 nm are degraded faster than VCSEL's emitting laser light at a wavelength of 850 nm.

[0011]

Further, the present applicants have found that internal stress occurs in the ion injection type or selective-oxidation type VCSEL's, which are currently becoming mainstream, since the oxidized current confinement layer becomes a completely different material (e.g., Al_2O_3) from the crystals around the oxidized current confinement layer. The internal stress lowers crystal quality and reliability of the laser.

[0012]

The present invention has been developed in view of the above circumstances. It is an object of the present invention is to provide a highly reliable surface emitting semiconductor laser element that emits laser light in an oscillation wavelength band of 730 to 820 nm.

[0013]

[Means for Solving the Problem]

A surface emitting semiconductor laser element of the present invention that emits laser light from a surface thereof comprises: a GaAs substrate; semiconductor layers which are formed above the GaAs substrate parallel to the above surface; and a pair of

electrodes which inject current into an active layer. The semiconductor layers include: a lower mirror which is realized by a semiconductor multilayer film formed above the GaAs substrate, and which constitutes an optical resonator; the active layer formed above the lower mirror; a current confinement layer of a selective-oxidation type or an ion injection type formed above the active layer; and an upper mirror which is realized by a semiconductor multilayer film formed above the current confinement layer, and which constitutes the optical resonator. The active layer includes: a quantum well made of InGaAsP having a first forbidden bandwidth; and sublayers arranged adjacent to the quantum well and made of InGaP or InGaAsP which has a second forbidden bandwidth greater than the first forbidden bandwidth. The lower mirror and the upper mirror are made of AlGaAs.

[0014]

It is desirable for each of the quantum well and the InGaP or InGaAsP sublayers to have a composition that lattice matches with GaAs.

[0015]

The quantum well may have a composition that causes compressive strain with respect to GaAs, and each of the InGaP or InGaAsP sublayers may have a composition that lattice matches with GaAs.

[0016]

The quantum well may have a composition that causes compressive strain with respect to GaAs, and each of the InGaP or InGaAsP sublayers may have a composition that causes tensile strain with respect to GaAs.

[0017]

The quantum well may have a composition that causes tensile strain with respect to GaAs, and each of the InGaP or InGaAsP sublayers may have a composition that lattice matches with GaAs.

[0018]

The quantum well may have a composition that causes tensile strain with respect to GaAs, and each of the InGaP or InGaAsP sublayers may have a composition that causes compressive strain with respect to GaAs.

[0019]

The InGaP or InGaAsP sublayers may be barrier layers.

[0020]

The InGaP or InGaAsP sublayers may be spacer layers. It is desirable for the oscillation wavelength band of the laser light to be within a range of 730nm to 820nm. It is further desirable for the oscillation wavelength band of the laser light to be within a range of 770nm to 800nm.

[0021]

The "selective-oxidation type current confinement layer" is a layer which is formed to confine current injected into the active layer, by selectively oxidizing portions of a semiconductor layer which is easily subject to selective oxidation (e.g., an AlAs layer or an aluminum-rich AlGaAs layer) except for a current injection area so as to insulate or semi-insulate the portions of the semiconductor layer by the oxidation.

[0022]

The "ion injection type current confinement layer" is a layer which is formed to confine current injected into the active layer, by injecting ions such as protons into portions of a semiconductor layer except for a current injection region so as to insulate or semi-insulate the portions of the semiconductor layer by the injection.

[0023]

The phrase "lattice matches with GaAs" refers to a state in which the absolute value of an amount $(c-c_s)/c_s$ is equal to or smaller than 0.003, when the GaAs substrate has a lattice constant c_s, and a layer grown

above the substrate has a lattice constant c.

[0024]

The phrase "causes compressive strain with respect to GaAs" refers to a state in which the value of the amount $(c-c_s)/c_s$ is greater than 0.003 and a layer grown above the GaAs substrate has a lattice constant c greater than the lattice constant c_s of the GaAs substrate. The phrase "causes tensile strain with respect to GaAs" refers to a state in which the value of the amount $(c-c_s)/c_s$ is less than -0.003, and a layer grown above the GaAs substrate has a lattice constant c smaller than the lattice constant c_s of the GaAs substrate.

[0025]

[Advantageous Effects of the Invention]

Since the active layer in the surface emitting semiconductor laser element according to the present invention includes the quantum well made of InGaAsP and the sublayers made of InGaP or InGaAsP and arranged adjacent to the quantum well, it is possible to prevent the influence of strain caused by the current confinement layer of the selective-oxidation type or the ion injection type. Therefore, lowering of crystal quality caused by the strain can be prevented, and high reliability can be achieved.

[0026]

The present invention having the above advantages has been made based on a finding by the present inventors that active layers made of InGaAsP and InGaP sublayers in surface emitting semiconductor laser elements are resistant to strain occurring in layers outside the active layers from the viewpoint of reliability, as described in detail below.

[0027]

Two semiconductor laser elements (A) and (B) were produced by MOCVD (metal organic chemical vapor deposition). In the semiconductor laser element (A), an

n-type GaAs buffer layer (having a thickness of 0.2 μm and being doped with Si of 1 X 10^{18} cm^{-3}), an n-type $Al_{0.6}Ga_{0.4}As$ cladding layer (having a thickness of 1.5 μm and being doped with Si of 8 X 10^{17} cm^{-3}), an undoped $Al_{0.3}Ga_{0.7}As$ optical guide layer (having a thickness of 0.2 μm), an undoped $Al_{0.08}Ga_{0.92}As$ single-quantum well active layer (having a thickness of 10 μm and a wavelength of 810 nm and lattice matching with the GaAs substrate), an undoped $Al_{0.3}Ga_{0.7}As$ optical guide layer (having a thickness of 0.2 μm), a p-type $Al_{0.6}Ga_{0.4}As$ cladding layer (having a thickness of 1.5 μm and being doped with Zn of 1 X 10^{18} cm^{-3}), a p-type GaAs cap layer (having a thickness of 0.2 μm and being doped with Zn of 5 X 10^{18} cm^{-3}), an SiO_2 film having a stripe opening corresponding to a current injection region and having a width of 50 μm, and a p electrode made of Ti/Pt/Au are formed on an n-type GaAs substrate (doped with Si of 1 X 10^{18} cm^{-3}). In addition, an n electrode made of AuGe/Au is formed on the back surface of the substrate. The semiconductor laser element (B) has an identical structure to the semiconductor laser element (A) except that the optical guide layers are made of InGaP, and the quantum well active layer is made of InGaAsP. Both of the semiconductor laser elements (A) and (B) have a resonator length of 750 μm. In each of the semiconductor laser elements (A) and (B), the forward end facet is coated so as to have a reflectance of 30%, and the back end facet is coated so as to have a reflectance of 95%. In addition, the bonding surface of each of the semiconductor laser elements (A) and (B) is bonded to a heat sink made of CuW with AuSn solder.

[0028]

Changes in driving current in each of the semiconductor laser elements (A) and (B) over time were measured during an aging test performed at an ambient temperature of 50°C with a constant output power of 500

mW, as indicated in Fig. 4. Although all samples of the semiconductor laser element (A) stopped oscillation within 1,000 hours, all samples of the semiconductor laser element (B) operated stably for a long time. However, when indium, which is soft and plastically deformable, is used as the soldering material, the stress imposed on the chips is small, and therefore the above difference in the lifetimes of the semiconductor laser elements (A) and (B) is not observed. That is, the above difference in the lifetimes is caused by external stress imposed by the AuSn solder, and the results of the aging tests indicated in Fig. 4 show that the semiconductor laser element in which the optical guide layers are made of InGaP or InGaAsP, and the quantum well active layer is made of InGaAsP is more resistant to the external stress than the semiconductor laser element in which the quantum well active layer is made of AlGaAs.

[0029]

In addition, according to the present invention, since the sublayers made of InGaP or InGaAsP are arranged adjacent to the quantum well, it is possible to prevent formation of a region where AlGaAs (of which the upper and lower mirrors are made) and InGaAsP (of which the quantum well is made) are in contact with each other. Since it is impossible to form a high-quality crystal in the region where AlGaAs and InGaAsP are in contact with each other, high reliability can be achieved by the prevention of formation of such a region.

[0030]

Further, when each of the quantum well and the InGaP or InGaAsP sublayers has a composition that lattice matches with GaAs, it is possible to achieve satisfactory crystal quality and high reliability.

[0031]

When the quantum well has a composition that causes compressive strain with respect to GaAs, and each of the

InGaP or InGaAsP sublayers has a composition that causes tensile strain with respect to GaAs, it is possible to compensate for the compressive strain in the quantum well with the tensile strain in the sublayers. Therefore, the crystal quality is improved, and satisfactory laser characteristics are achieved.

[0032]

When the quantum well has a composition that causes tensile strain with respect to GaAs, and each of the InGaP or InGaAsP sublayers has a composition that causes compressive strain with respect to GaAs, it is possible to compensate for the tensile strain in the quantum well with the compressive strain in the sublayers. Therefore, the crystal quality is improved, and satisfactory laser characteristics are achieved.

[0033]

[Embodiments of the Invention]

Embodiments of the present invention will be described in detail below with reference to the attached drawings.

[0034]

First, the surface emitting semiconductor laser element according to a first embodiment of the present invention will be described below with reference to Fig. 1, which shows a cross section of the surface emitting semiconductor laser element.

[0035]

As illustrated in Fig. 1, first, an n-type GaAs buffer layer 12 (which has a thickness of 100 nm and is doped with Si of 1 X 10^{18} cm^{-3}), an n-type $Al_{0.9}Ga_{0.1}As/Al_{0.3}Ga_{0.7}As$ lower semiconductor multilayer reflection film 13, an undoped InGaP spacer layer 14, a quantum well active layer 15, an undoped InGaP spacer layer 16, a p-type $Al_{0.5}Ga_{0.5}As$ spacer layer 17 (doped with C of 8 X 10^{17} cm^{-3}), a p-type AlAs layer 18 (which has a

thickness corresponding to a quarter wavelength and is doped with C of 2 X 10^{18} cm^{-3}), a p-type $Al_{0.5}Ga_{0.5}As$ spacer layer 19, a p-type $Al_{0.9}Ga_{0.1}As/Al_{0.3}Ga_{0.7}As$ upper semiconductor multilayer reflection film 20, and a p-type GaAs contact layer 21 (which has a thickness of 10 nm and is doped with C of 5 X 10^{19} cm^{-3}) are formed on an n-type GaAs substrate 11 by MOCVD. The n-type $Al_{0.9}Ga_{0.1}As/Al_{0.3}Ga_{0.7}As$ lower semiconductor multilayer reflection film 13 is constituted by 38.5 periods of alternating layers of a high-refractive-index film and a low-refractive-index film each having a thickness corresponding to a quarter wavelength and being doped with Si of 1 X 10^{18} cm^{-3}. The quantum well active layer 15 is constituted by three undoped InGaAsP quantum well layers each having a thickness of 10 nm and an oscillation wavelength of 780 nm and two undoped InGaP barrier layers each having a thickness of 5 nm. The p-type $Al_{0.9}Ga_{0.1}As/Al_{0.3}Ga_{0.7}As$ upper semiconductor multilayer reflection film 20 is constituted by 28 periods of alternating layers of a high-refractive-index film and a low-refractive-index film each having a thickness corresponding to a quarter wavelength and being doped with C of 2 X 10^{18} cm^{-3}.

[0036]

In the first embodiment, all of the layers made of InGaP or InGaAsP have a composition that lattice matches with the GaAs substrate.

[0037]

Next, an area of the p-type GaAs contact layer 21 corresponding to an light emitting region is removed by etching. In order to form an oscillation region, portions of the above semiconductor layers except for a cylindrical region having a diameter r_2 of 50 μm are removed by etching to a mid-thickness of the n-type $Al_{0.9}Ga_{0.1}As/Al_{0.3}Ga_{0.7}As$ lower semiconductor multilayer reflection film 13. Then, heat treatment is performed at

390°C for ten minutes in a furnace into which heated steam is introduced, so that a portion 18a of the p-type AlAs layer 18 excluding a current injection region is selectively oxidized, i.e., the round-shaped current injection region is formed. The current injection region has a diameter r_1 of 12 μm.

[0038]

Thereafter, an SiO_2 protective film 22 is formed over the areas which are exposed by the etching performed to produce the above cylindrical region, and then a portion of the SiO_2 protective film 22 corresponding to the current injection region is removed. Subsequently, a p electrode 23 made of Ti/Pt/Au is formed on the p-type GaAs contact layer 21, and an n electrode 24 made of AuGe/Ni/Au is formed on the back surface of the n-type GaAs substrate 11. That is, the p electrode 23 is formed by depositing Ti, Pt, and Au in this order, and the n electrode 24 is formed by depositing AuGe, Ni and Au in this order.

[0039]

In the above structure, the spacer layers are arranged so as to adjust the optical thickness of the layers between the lower and upper semiconductor multilayer reflection films and locate a loop portion of a standing wave over the active layer, and have an effect of lowering the threshold.

[0040]

In the first embodiment, the spacer layers include the undoped InGaP spacer layer 14 which is arranged on the substrate side of the active layer 15, and the undoped InGaP spacer layer 16, the p-type $Al_{0.5}Ga_{0.5}As$ spacer layer 17, and the p-type $Al_{0.5}Ga_{0.5}As$ spacer layer 19 which are arranged on the opposite side of the active layer 15. If layers made of AlGaAs (such as the n-type $Al_{0.9}Ga_{0.1}As/Al_{0.3}Ga_{0.7}As$ lower semiconductor multilayer reflection film 13 and the p-type $Al_{0.5}Ga_{0.5}As$ spacer layer

17) exist in contact with the undoped InGaAsP quantum well layer in the quantum well active layer 15, it is impossible to form satisfactory crystal interfaces. However, since the undoped InGaP spacer layer 14 and the undoped InGaP spacer layer 16 are provided in the first embodiment, it is possible to make the interfaces with the undoped InGaAsP quantum well layer have satisfactory quality, and to improve the reliability of the surface emitting semiconductor laser element.

[0041]

In addition, since the p-type AlAs layer 18 having a function of a current confinement layer is arranged between the p-type $Al_{0.5}Ga_{0.5}As$ spacer layer 17 and the p-type $Al_{0.5}Ga_{0.5}As$ spacer layer 19, the selective oxidation characteristics at the interfaces between the AlGaAs layers and the AlAs layer become satisfactory, and highly precise current confinement is enabled.

[0042]

The p-type $Al_{0.5}Ga_{0.5}As$ spacer layer 17 and the p-type $Al_{0.5}Ga_{0.5}As$ spacer layer 19 may alternatively both be formed of either InGaP or InGaAsP, or each may be formed of either InGaP or InGaAsP.

[0043]

Note that the composition of the undoped InGaP spacer laers 14 and 16 may be undoped InGaAsP.

[0044]

In addition, the number of barrier layers may be increased to four, and barrier layers made of undoped InGaP or undoped InGaAsP may be provided such that both ends of the active layer are barrier layers, instead of providing the undoped InGaP spacer layers 14 and 16.

[0045]

Although the n electrode 24 is formed on the back surface of the n-type GaAs substrate 11 in the first embodiment, alternatively, the etching for producing the aforementioned cylindrical region may be performed to

such a depth so as to expose one of the n-type layers, and form an n electrode on the exposed n-type layer. For example, it is possible to expose the n-type $Al_{0.9}Ga_{0.1}As/Al_{0.3}Ga_{0.7}As$ lower semiconductor multilayer reflection film 13 and form the n electrode on the exposed surface of the lower semiconductor multilayer reflection film 13.

[0046]

Although the layers constituting the surface emitting semiconductor laser element according to the first embodiment are grown by MOCVD, the layers may be formed by molecular beam epitaxy (MBE) using a solid or gas source.

[0047]

Although the number of quantum well layers in the surface emitting semiconductor laser element according to the first embodiment is three, the surface emitting semiconductor laser element according to the first embodiment may include any number of quantum well layers.

[0048]

The protective film 22 may be made of Al_2O_3, Si_xN_y or the like, instead of SiO_2.

[0049]

The p electrode may be made by depositing chromium and gold in this order, or depositing AuGe and gold in this order. The n electrode may be made by depositing AuGe and gold in this order.

[0050]

Although the p-type AlAs layer 18 other than the current injection region is selectively oxidized for current confinement in the first embodiment, i.e., the surface emitting semiconductor laser element according to the first embodiment includes a selective-oxidation type current confinement structure, alternatively, it is possible to adopt an ion injection type current confinement structure, in which regions other than the

current injection region are insulated by injecting protons or the like into the regions other than the current injection region, or semi-insulated by injecting other ions into the above regions other than the current injection region.

[0051]

As described above, the surface emitting semiconductor laser element according to the first embodiment comprises the n-type GaAs substrate 11, the semiconductor layers formed on the n-type GaAs substrate 11, and the pair of electrodes (the p electrode 23 and the n electrode 24) for injecting current into the quantum well active layer 15, where the semiconductor layers include the n-type GaAs buffer layer 12, the n-type $Al_{0.9}Ga_{0.1}As/Al_{0.3}Ga_{0.7}As$ lower semiconductor multilayer reflection film 13, the undoped InGaP spacer layer 14, the quantum well active layer 15, the undoped InGaP spacer layer 16, the p-type $Al_{0.5}Ga_{0.5}As$ spacer layer 17, the p-type AlAs layer 18, the p-type $Al_{0.5}Ga_{0.5}As$ spacer layer 19, the p-type $Al_{0.9}Ga_{0.1}As/Al_{0.3}Ga_{0.7}As$ upper semiconductor multilayer reflection film 20, and the p-type GaAs contact layer 21 which are formed in this order, the quantum well active layer 15 includes the undoped InGaAsP quantum well layers and the undoped InGaP barrier layers, and the portion 18a of the p-type AlAs layer 18 other than the current injection region is oxidized. Laser light is emitted from the exposed surface of the p-type $Al_{0.9}Ga_{0.1}As/Al_{0.3}Ga_{0.7}As$ upper semiconductor multilayer reflection film 20. The n-type $Al_{0.9}Ga_{0.1}As/Al_{0.3}Ga_{0.7}As$ lower semiconductor multilayer reflection film 13 and the p-type $Al_{0.9}Ga_{0.1}As/Al_{0.3}Ga_{0.7}As$ upper semiconductor multilayer reflection film 20 realize mirrors constituting an optical resonator.

[0052]

In the surface emitting semiconductor laser element according to the first embodiment, the light emitting

region having the cylindrical shape protrudes upward. Alternatively, it is possible to realize the light emitting region by forming a doughnut-shaped trench around the light emitting region, and leaving the semiconductor layers on the outer side of the doughnut-shaped trench so that the surface emitting semiconductor laser element except for the doughnut-shaped trench has substantially a uniform height. For example, the doughnut-shaped trench has an inner diameter r_2 of 50 μm and an outer diameter r_3 of 80 μm as illustrated in Fig. 2. Since the portion of the surface emitting semiconductor laser element on the outer side of the doughnut-shaped trench has the same height as the light emitting region, the surface emitting semiconductor laser element having the structure illustrated in Fig. 2 is advantageous for handling of the element during a manufacturing process, wire bonding at the time of mounting, and the like.

[0053]

Note that only one light emitting region is provided in the surface emitting semiconductor laser element according to the first embodiment. Alternatively, it is possible to arrange a plurality of light emitting regions in a single element by forming a plurality of doughnut-shaped trenches.

[0054]

Next, a semiconductor laser according to a second embodiment of the present invention will be described. Figure 3 is a sectional view of the semiconductor laser according to the second embodiment.

[0055]

As illustrated in Fig. 3, first, an n-type GaAs buffer layer 32 (which has a thickness of 100 nm and is doped with Si of 1 X 10^{18} cm^{-3}), an n-type $Al_{0.9}Ga_{0.1}As/Al_{0.3}Ga_{0.7}As$ lower semiconductor multilayer reflection film 33, an undoped InGaP spacer layer 34, a

quantum well active layer 35, an undoped InGaP spacer layer 36, a p-type AlAs layer 37 (which has a thickness corresponding to a quarter wavelength and is doped with C of 2 X 10^{18} cm^{-3}), a p-type $Al_{0.5}Ga_{0.5}As$ spacer layer 38, a p-type $Al_{0.9}Ga_{0.1}As/Al_{0.3}Ga_{0.7}As$ upper semiconductor multilayer reflection film 39, and a p-type GaAs contact layer 40 (which has a thickness of 10 nm and is doped with C of 1 X 10^{20} cm^{-3}) are formed in this order on an n-type GaAs substrate 31 by MOCVD. The n-type $Al_{0.9}Ga_{0.1}As/Al_{0.3}Ga_{0.7}As$ lower semiconductor multilayer reflection film 33 is constituted by 40.5 periods of alternating layers of a high-refractive-index film and a low-refractive-index film each having a thickness corresponding to a quarter wavelength and being doped with Si of 1 X 10^{18} cm^{-3}. The quantum well active layer 35 is constituted by four undoped InGaAsP quantum well layers each having a thickness of 8 nm and an oscillation wavelength of 780 nm and three undoped InGaP barrier layers each having a thickness of 5 nm. The p-type $Al_{0.9}Ga_{0.1}As/Al_{0.3}Ga_{0.7}As$ upper semiconductor multilayer reflection film 39 is constituted by 29 periods of alternating layers of a high-refractive-index film and a low-refractive-index film each having a thickness corresponding to a quarter wavelength and being doped with C of 2 X 10^{18} cm^{-3}.

[0056]

In the second embodiment, all of the layers made of InGaP or InGaAsP have a composition that lattice matches with the GaAs substrate.

[0057]

Next, an area of the p-type GaAs contact layer 40 corresponding to a light emitting region is removed by etching. In order to form an oscillation region, portions of the semiconductor layers except for a cylindrical region having a diameter r_2 of 30 μm are removed by etching to the upper boundary of the p-type $Al_{0.5}Ga_{0.5}As$

spacer layer 36. Then, heat treatment is performed at 390°C for eight minutes in a furnace into which heated steam is introduced, so that a portion of the p-type AlAs layer 37 excluding a current injection region is selectively oxidized, i.e., the round-shaped current injection region is formed. The current injection region has a diameter r_1 of 8 μm.

[0058]

Thereafter, an SiO_2 protective film 41 is formed over the areas which are exposed by the etching performed to produce the above cylindrical region, and then a portion of the SiO_2 protective film 41 corresponding to the current injection region is removed. Subsequently, a p electrode 42 made of Ti/Pt/Au is formed on the p-type GaAs contact layer 40, and an n electrode 43 made of AuGe/Ni/Au is formed on the back surface of the n-type GaAs substrate 31. That is, the p electrode 42 is formed by depositing Ti, Pt, and Au in this order, and the n electrode 43 is formed by depositing AuGe, Ni and Au in this order.

[0059]

In the above structure, the p-type $Al_{0.5}Ga_{0.5}As$ spacer layer 38 is arranged so as to adjust the optical thickness of the layers between the lower and upper semiconductor multilayer reflection films 33 and 39 and locate a loop portion of a standing wave over the active layer.

[0060]

As described above, the surface emitting semiconductor laser element according to the second embodiment comprises the n-type GaAs substrate 31, the semiconductor layers formed on the n-type GaAs substrate 31, and the pair of electrodes (the p electrode 42 and the n electrode 43) for injecting current into the quantum well active layer 35, where the semiconductor layers include the n-type GaAs buffer layer 32, the n-

type $Al_{0.9}Ga_{0.1}As/Al_{0.3}Ga_{0.7}As$ lower semiconductor multilayer reflection film 33, the undoped InGaP spacer layer 34, the quantum well active layer 35, the undoped InGaP spacer layer 36, the p-type AlAs layer 37, the p-type $Al_{0.5}Ga_{0.5}As$ spacer layer 38, the p-type $Al_{0.9}Ga_{0.1}As/Al_{0.3}Ga_{0.7}As$ upper semiconductor multilayer reflection film 39, and the p-type GaAs contact layer 40 which are formed in this order, the quantum well active layer 35 includes the undoped InGaAsP quantum well layers and the undoped InGaP barrier layers, and the portion of the p-type AlAs layer 37 other than the current injection region is oxidized. Laser light is emitted from the exposed surface of the p-type $Al_{0.9}Ga_{0.1}As/Al_{0.3}Ga_{0.7}As$ upper semiconductor multilayer reflection film 39. The n-type $Al_{0.9}Ga_{0.1}As/Al_{0.3}Ga_{0.7}As$ lower semiconductor multilayer reflection film 33 and the p-type $Al_{0.9}Ga_{0.1}As/Al_{0.3}Ga_{0.7}As$ upper semiconductor multilayer reflection film 39 realize mirrors constituting an optical resonator. Similar to the first embodiment, acceleration of deterioration due to strain in the current confinement layer can be prevented by the provision of the undoped InGaAsP quantum well layers and the undoped InGaP barrier layers in the active layer. Therefore, it is possible to achieve high reliability.

[0061]

The barrier layers in the first and second embodiments are made of InGaP, which is a ternary mixed crystal. Alternatively, all or a portion of the barrier layers may be made of InGaAsP, which is a quaternary mixed crystal. In the case where all or a portion of the barrier layers are made of InGaAsP containing some quantity (not exceeding about 5%) of As, it is possible to make the flatness of the surface of grown InGaAsP higher than that of InGaP by adjusting a crystal growth condition such as growth temperature or crystal orientation. Therefore, in this case, the high flatness

increases the emission efficiency, and decreases the deterioration rate.

[0062]

Each of the quantum well layers and the barrier layers in the first and second embodiments is made of InGaAsP or InGaP which has a composition that lattice matches with GaAs. Alternatively, it is possible to form each of the quantum well layers of InGaAsP which has a composition that causes compressive strain with respect to GaAs, and each of the barrier layers of InGaAsP or InGaP which has a composition that lattice matches with GaAs.

[0063]

As a further alternative, it is possible to form each of the quantum well layers of InGaAsP which has a composition that causes compressive strain with respect to GaAs, and each of the barrier layers of InGaAsP or InGaP which has a composition that causes tensile strain with respect to GaAs.

[0064]

As still another alternative, it is possible to form each of the quantum well layers of InGaAsP which has a composition that causes tensile strain with respect to GaAs, and each of the barrier layers of InGaAsP or InGaP which has a composition that lattice matches with GaAs.

[0065]

As yet another alternative, it is possible to form each of the quantum well layers of InGaAsP which has a composition that causes tensile strain with respect to GaAs, and each of the barrier layers of InGaAsP or InGaP which has a composition that causes compressive strain with respect to GaAs. According to the present invention, the reliability of VCSEL's having a selective-oxidation type or ion injection type current confinement structure (which are superior in performance and suitable for mass production) can be improved. Therefore, it is possible to

promote realization of high-speed optical-fiber communications at transmission rates exceeding 1 Gbps in automotive, home, HDTV, and other applications.

[Brief Description of the Drawings]

[Figure 1] a cross-sectional view of a surface emitting semiconductor laser element according to a first embodiment of the present invention.

[Figure 2] a cross-sectional view of an example of a variation of the surface emitting semiconductor laser element according to the first embodiment of the present invention.

[Figure 3] a cross-sectional view of a surface emitting semiconductor laser element according to a second embodiment of the present invention.

[Figure 4] a graph indicating the results of aging reliability tests of a semiconductor laser element (A) having an AlGaAs active layer and a semiconductor laser element (B) having an InGaAsP active layer.

[Explanation of the Reference Numerals]

11 n-type GaAs substrate

12 n-type GaAs buffer layer

13 n-type $Al_{0.9}Ga_{0.1}As/Al_{0.3}Ga_{0.7}As$ lower semiconductor multilayer reflection film

14 undoped InGaP spacer layer 14

15 quantum well active layer

16 undoped InGaP spacer layer 16

17 p-type $Al_{0.5}Ga_{0.5}As$ spacer layer

18 p-type AlAs layer

19 p-type $Al_{0.5}Ga_{0.5}As$ spacer layer

20 p-type $Al_{0.9}Ga_{0.1}As/Al_{0.3}Ga_{0.7}As$ upper semiconductor multilayer reflection film

21 p-type GaAs contact layer

22 SiO_2 protective film

23 Ti/Pt/Au p electrode

24 AuGe/Ni/Au n electmode

[Name of Document] Abstract

[Abstract]
[Objective]

To obtain high reliability in a surface emitting semiconductor laser element that emits light in the 780nm band.

[Constitution]

An n-type GaAs buffer layer 12, an n-type $Al_{0.9}Ga_{0.1}As/Al_{0.3}Ga_{0.7}As$ lower semiconductor multilayer reflection film 13, an undoped InGaP spacer layer 14, a quantum well layer active layer 15, an undoped InGaP spacer layer 16, a p-type $Al_{0.5}Ga_{0.5}As$ spacer layer 17, a p-type AlAs layer 18, a p-type $Al_{0.5}Ga_{0.5}As$ spacer layer 19, a p-type $Al_{0.9}Ga_{0.1}As/Al_{0.3}Ga_{0.7}As$ upper semiconductor multilayer reflection film 20, and a p-type contact layer 21 are stacked in this order on an n-type GaAs substrate 11. The quantum well active layer 15 includes an undoped InGaAsP quantum well layer and undoped InGaP barrier layers. Next, an area of the p-type GaAs contact layer 21 corresponding to the upper portion of a light emitting region is removed by etching. Further etching is performed through a portion of the n-type $Al_{0.9}Ga_{0.1}As/Al_{0.3}Ga_{0.7}As$ lower semiconductor multilayer reflection film 13, to form a cylindrical region having a diameter of 50μm. Then, a portion 18a of the p-type AlAs layer 18 excluding a current injection region is selectively oxidized.

[Selected Figure]Figure 1

FIG.1

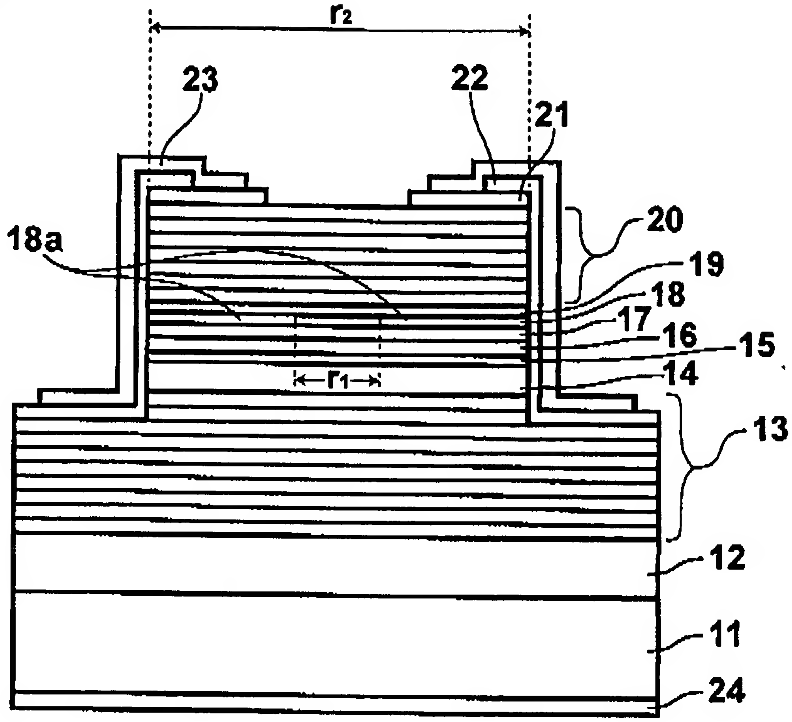


FIG.2

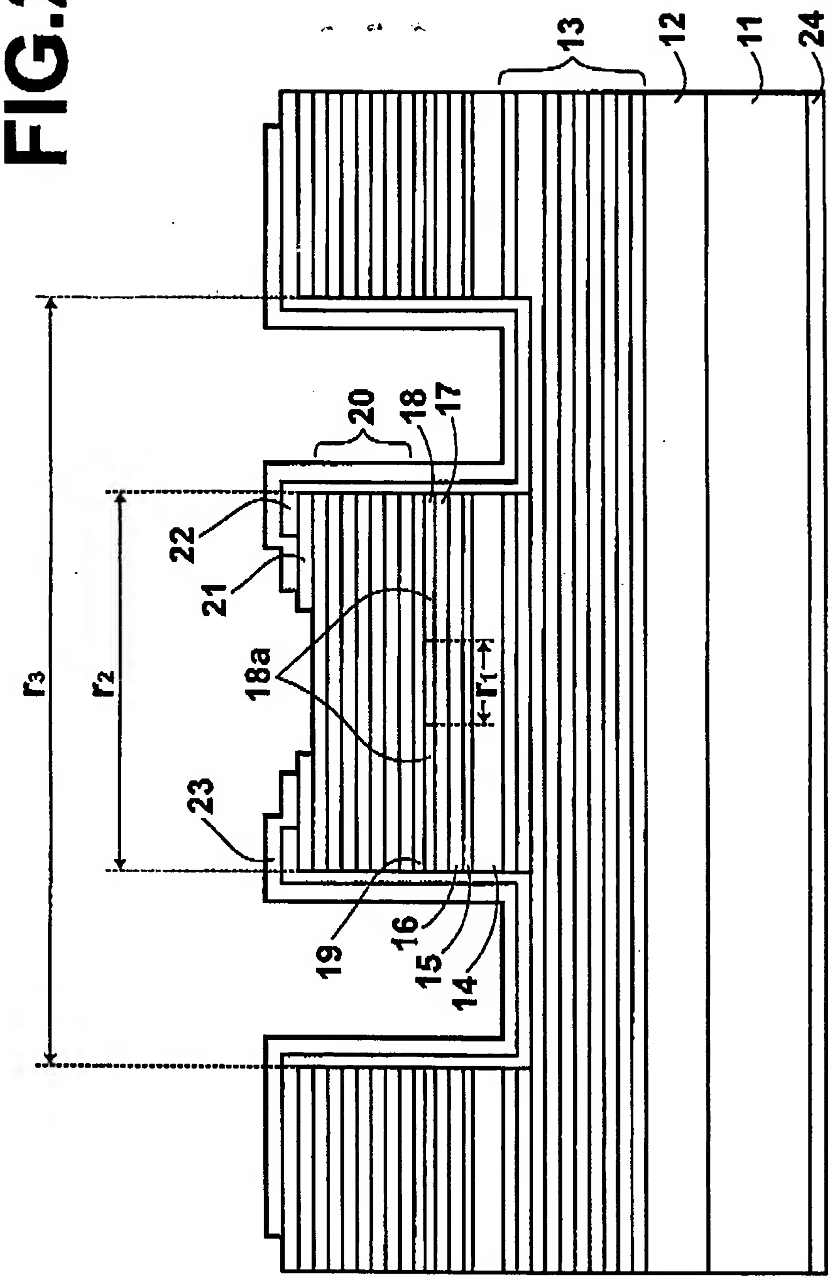


FIG.3

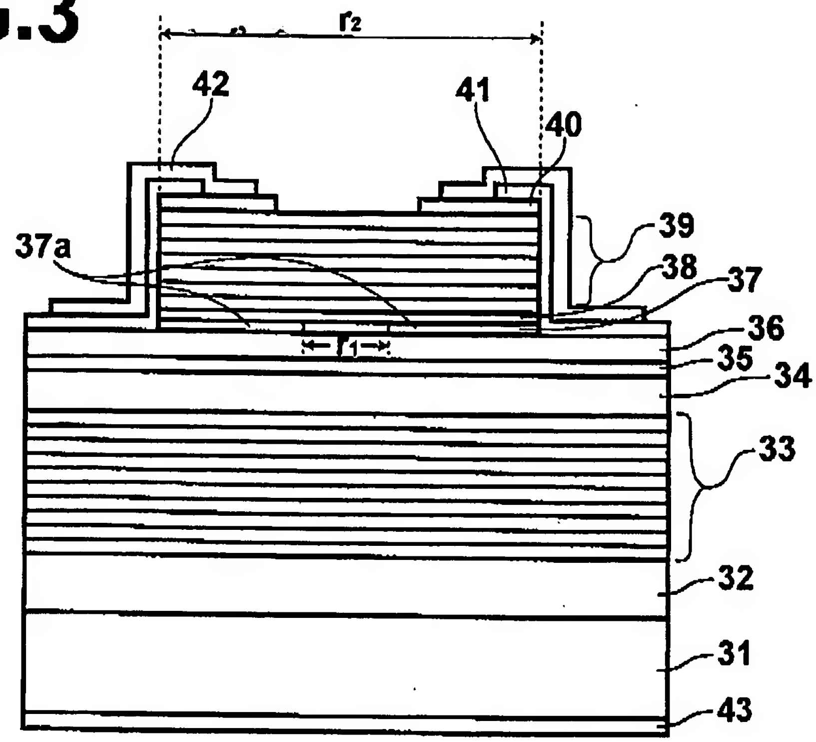
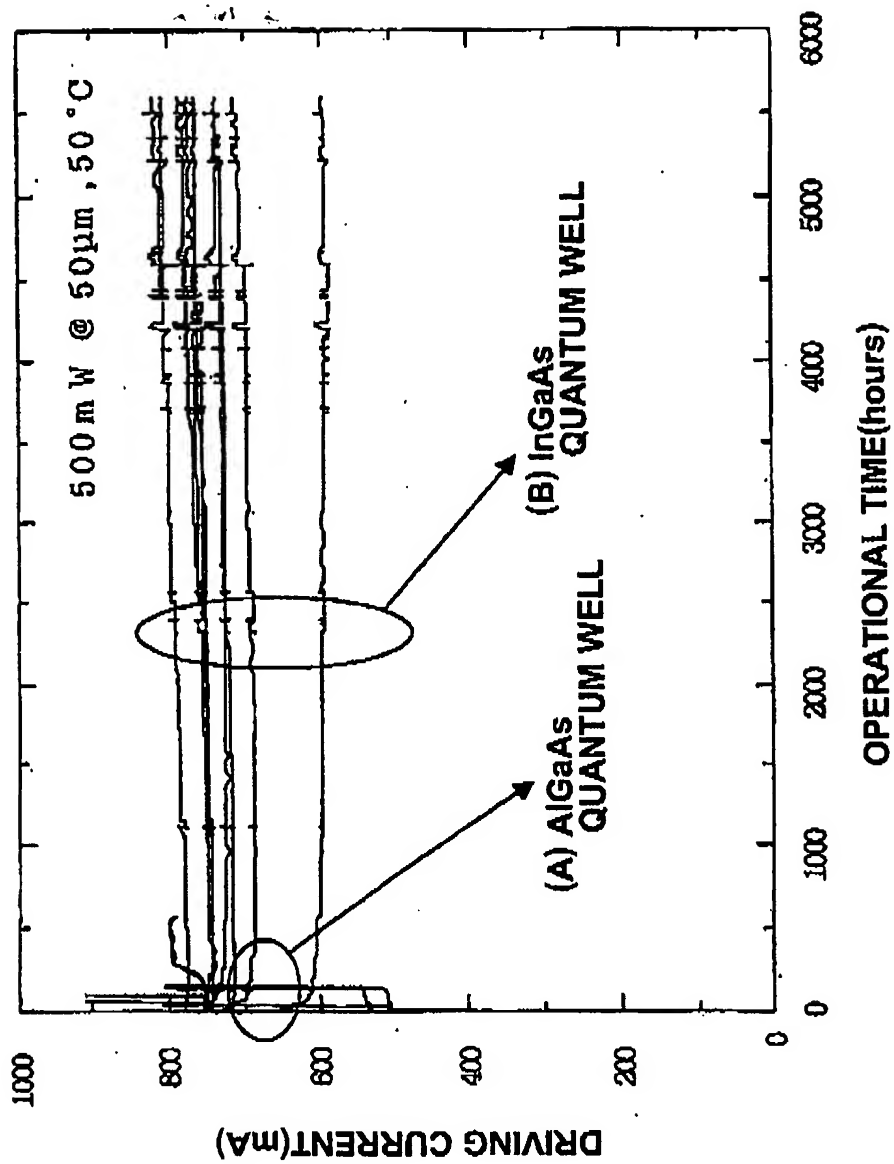


FIG.4


500mW @ 50μm, 50°C
(B) InGaAs QUANTUM WELL
(A) AlGaAs QUANTUM WELL
DRIVING CURRENT(mA)
1000
800
600
400
200
0
OPERATIONAL TIME(hours)
0
1000
2000
3000
4000
5000
6000